

CHAPTER 1

INTRODUCTION

1-1. Purpose.

a. Multi-Phase Extraction. Multi-Phase Extraction (MPE) is a rapidly emerging, in-situ remediation technology for simultaneous extraction of vapor phase, dissolved phase and separate phase contaminants from vadose zone, capillary fringe, and saturated zone soils and groundwater. It is a modification of soil vapor extraction (SVE) and is most commonly applied in moderate permeability soils.

b. Engineer Manual. This Engineer Manual (EM) provides practical guidance for evaluation of the feasibility and applicability of MPE for remediation of contaminated soil and groundwater and describes design and operational considerations for MPE systems. The document is primarily intended to set USACE technical policy on the use of the technology and to help prevent incorrect MPE application or its use in inappropriate settings. By setting out technically sound design principles, it will be useful to engineers, geologists, and project managers involved with subsurface remediation. It is meant to be a companion manual to the Soil Vapor Extraction and Bioventing (EM 1110-1-4001, 30 November 1995) and the In-Situ Air Sparging (EM 1110-1-4005, 16 June 1997) EMs, which will be referenced as appropriate. Many of the aboveground design aspects of MPE and SVE are similar.

1-2. Applicability. This EM applies to all United States Army Corps of Engineers (USACE) commands having civil works and/or military programs hazardous, toxic, or radioactive waste (HTRW) responsibilities.

1-3. References.

a. This EM (Baker and Becker 1999) covers all aspects of MPE but cannot include detailed discussion of all MPE issues. Where engineering design is similar to SVE, the two related EMs referenced above will be very useful. There are other publications that summarize or give detailed insights into important aspects of MPE. An extensive list and reference details are provided in Appendix A. The following references are suggested as key supplementary sources of information on MPE:

Subject

Technology Overview

Reference

Blake and Gates 1986
Kittel et al. 1994
Leeson et al. 1995
Baker 1995
Keet 1995
USEPA 1995
API 1996
USEPA 1997a

Important Physical, Biological and Chemical Parameters

Farr et al. 1990
Lenhard and Parker 1990
Newell et al. 1995
Pankow and Cherry 1996
Hillel 1998

Subject

Reference

Pilot Testing and Design

USEPA 1996a
Parker et al. 1996
Battelle 1997
Baker and Groher 1998

Modeling

Parker 1989
Parker 1995
Parker et al. 1996
Beckett and Huntley 1998
Ruiz et al. 1997

Equipment Specification and Operation

Crane Valve Co. 1988
Hydraulic Institute 1991
Hydraulic Institute 1994
Karassik et al. 1986
Perry and Green 1984
Suthersan 1997

Evaluation of System Performance

Kittel et al. 1997
Baker and Groher 1998

b. Periodicals. Periodicals that occasionally feature articles on MPE and related technologies include:

- Ground Water (Association of Ground Water Scientists and Engineers).
- Ground Water Monitoring and Remediation (Association of Ground Water Scientists and Engineers).
- Pollution Engineering (Cahners Business Information Division of Reed Elsevier, Inc.).
- Pumps and Systems (AES Marketing, Inc.).

1-4. Background.

a. In-situ soil and groundwater remediation techniques are being relied on more and more frequently as methods that are less expensive than excavation and that do not simply move the contamination to another location. However, the limitations of many solitary in-situ technologies are becoming more apparent, especially longer-than-expected remediation times. In addition, solitary technologies may only treat one phase of the contamination when, in fact, the contamination is often spread through multiple phases and zones. For example, SVE and bioventing treat only the vadose zone and groundwater pump-and-treat removes dissolved material only from the saturated zone. Most separate (free) phase [Lighter (than water) Non-Aqueous Phase Liquid (LNAPL)] recovery systems rely on gravity alone to collect and pump the LNAPL. In contrast, MPE can extract:

- Groundwater containing dissolved constituents from the saturated zone.
- Soil moisture containing dissolved constituents from the unsaturated zone.
- LNAPL floating on the groundwater.
- Non-drainable LNAPL in soil.
- Perched or pooled Dense Non-Aqueous Phase Liquid (DNAPL), under some conditions.
- Soil gas containing volatile contaminants.

It is therefore a technology that finds its widest use in source areas.

b. In general, MPE works by applying a high vacuum (relative to SVE systems) to a well or trench that intersects the vadose zone, capillary fringe and saturated zone. Because the resulting subsurface pressure is less than atmospheric, groundwater rises and, if drawn into the well, is extracted and treated aboveground before discharge or reinjection. If liquid and gas are extracted within the same conduit (often called a suction pipe or drop tube), this form of MPE is often called "bioslurping" (when used for vacuum-enhanced LNAPL recovery), or "two-phase extraction" (TPE, often when used to address chlorinated solvents). If separate conduits for vapor and liquids are used, some call the technology "dual-phase extraction" (DPE). (These terms, "two-phase extraction" and "dual-phase extraction" more commonly refer to situations where there is no LNAPL.) LNAPL floating on the water table will also flow into the well screen and be removed. Due to the imposed vacuum, soil moisture and NAPL retained by capillary forces within the soil can, to some degree, also move to the well for collection and removal. The groundwater level may be lowered, thereby creating a larger vadose zone that can be treated by the SVE aspect of MPE. The soil gas that is extracted is, if necessary, conveyed to a vapor-phase treatment system (i.e., activated carbon, catalytic oxidation, etc.), prior to its discharge.

c. Because air movement through the unsaturated zone is induced during MPE, oxygen can stimulate the activity of indigenous aerobic microbes, thereby increasing the rate of natural aerobic biodegradation of both volatile and non-volatile hydrocarbon contamination.

d. MPE is being evaluated by several departments of the U.S. government. USEPA's Superfund Innovative Technology Evaluation (SITE) program is supporting a study of bioslurping by Battelle Memorial Institute, Columbus, OH, at a fuel tank farm. The U.S. Air Force "recommends MPE as a potentially valuable enhancement for the SVE option under the presumptive remedy for sites with volatile organic compounds (VOCs) in soil" (USEPA 1997a). In 1997, the USEPA issued ["Presumptive Remedy: Supplemental Bulletin on MPE Technology for VOCs in Soil and Groundwater"](#) (USEPA 1997a).

e. The application of MPE began the first time that either groundwater or LNAPL was extracted by a vacuum. Vacuum was applied to oil wells in the 1860s to improve LNAPL recovery from subsurface reservoirs (Lindsley 1926). One of

the first mentions of MPE as a new remediation technology appears to be by Blake and Gates (1986). At this time, MPE is utilized less often than the more established in-situ techniques such as SVE, bioventing and air sparging. The use of MPE as a deliberately applied remediation technology is expected to increase.

f. Critical aspects that govern the effectiveness of an MPE system are being researched and reported in conference proceedings and technical journals (some shown above). Innovative field techniques, such as neutron probe measurements and recoverable free phase product estimates, are refining the ability to measure the effective zone of influence (ZOI). It is anticipated that as more field data become available, the understanding of the mechanisms and processes induced by MPE will increase, as well as the ability to predict and measure its effectiveness.

g. One of the difficulties encountered with MPE is the tendency to form emulsions of LNAPL and groundwater that may need to be "broken" or separated before subsequent treatment or disposal.

1-5. EM Scope. As mentioned in paragraph 1-1b, the primary focus of this EM (Baker and Becker 1999) is to provide guidance for assessing the feasibility and applicability of MPE. The EM is also meant to assist engineering and technical staff experienced in remediation design to develop MPE design, including construction drawings and specifications. Because MPE technology is still evolving, this EM is intended to consolidate existing guidance and to stimulate the acquisition and reporting of new information that will continue to refine the technology. Although computer modeling is discussed, exhaustive coverage of analytical and numerical modeling of the processes occurring during MPE is beyond the scope of this EM. The reader should keep in mind that the use of MPE as a site remediation tool is a relatively new technology. Design and operation are highly dependent on site conditions, and designs will improve as more information becomes available and more experience is shared.

1-6. EM Organization. This EM is structured to show the progression from initial technology selection through testing, design, implementation and closure. Following this introductory chapter, Chapter 2 provides a more detailed description of MPE and its underlying physical processes. Recommendations for site characterization and feasibility evaluations are presented in Chapter 3. Strategy and guidance for pilot-scale testing are provided in Chapter 4, and full-scale design considerations are presented in Chapter 5. Chapter 6 provides guidance on preparing design documents and specifications. Issues associated with system start-up and long-term operation and maintenance are discussed in Chapter 7, and system shutdown procedures and confirmation of clean-up are introduced in Chapter 8. Chapter 9 presents other administrative issues associated with implementing MPE. Finally, Appendix A provides references cited in this document.

1-7. Resources.

a. Numerous resources are available to assist the designer in assessing the feasibility of MPE and designing an effective system. Resources include models for system design and optimization, technical journals that summarize case studies and recent technical developments, and electronic bulletin boards and databases that provide access to regulatory agency, academic, and commercial sources of information.

b. At this time, there are few computer models written specifically for MPE applications. Existing, related models, which are discussed in [paragraph 5-4](#), range from commercially available software to complex computer code requiring substantial computing ability. These models help the designer to understand what will occur relative to pressure distributions and subsurface flow when vacuums are applied. Modeling can be used to design a pilot test; optimize placement of MPE wells in a multiwell field; and estimate extracted liquid and vapor flow rates that determine the sizes of aboveground extraction and treatment equipment.

c. A table of federal bulletin boards and databases that contains information on SVE and bioventing (BV) is presented in the USACE Soil Vapor Extraction and Bioventing Engineer Manual ([EM 1110-1-4001](#)). The majority of these electronic resources also now contain some information on MPE. The following list gives a description and associated universal resource locator (URL) of several of these bulletin boards and/or databases that can be found on the World Wide Web.

- The Federal Remediation Technologies Roundtable (<http://www.frtr.gov>): Remediation Technologies Screening Matrix and Reference Guide, 3rd Edition.
- CLU-IN (<http://clu-in.org>): Hazardous Waste Clean-Up Information System provides information about innovative treatment technologies.
- REACH-IT (<http://www.epareachit.com>): Remediation and Characterization Innovative Technologies.
- TechDirect (<http://www.epa.gov/swertiol/techsub.htm>): Technology Information Service that highlights new publications and events of interest on site remediation and assessment.
- BioGroup (<http://biogroup.gzea.com>): Bioremediation Discussion Group.
- ATTIC (<http://www.epa.gov/gils/records/a00194.html>): Alternative Treatment Technology Information Center.
- Fielding Environmental Solutions (<http://aec-www.apgea.army.mil:8080/prod/usace/et/listweb.htm>): U.S. Army Environmental Center's (USAEC) Pollution Prevention and Environmental Technology Division (P2&ETD) site that provides information on recently published documents, field demonstrations of innovative technologies, and technology transfer efforts of the P2&ETD.
- GLOBALtechs (<http://www.globaltechs.com>): Online Site Remediation Technologies Directories.
- DNAPL in Groundwater Research Group (<http://civil.queensu.ca/environ/groundwater/refereed.htm>).

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- US Army Corps of Engineers TechInfo
(<http://www.hnd.usace.army.mil/techinfo/index.htm>): provides links to USACE publications and specifications.
- EPA Remediation Technologies Publications
(<http://www.epa.gov/swertiol/pubitech.htm>).